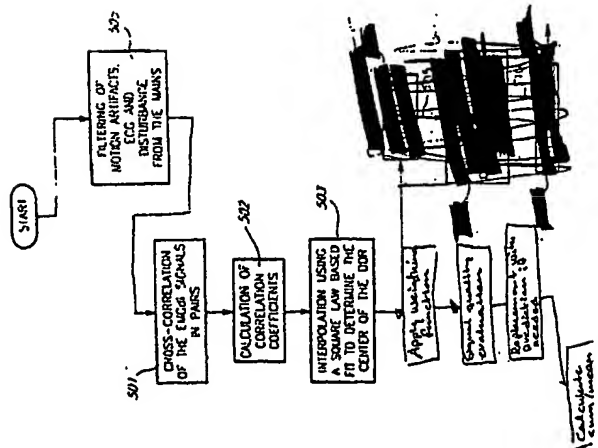


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(54) METHODE ET SYSTEME D'ANALYSE DE SIGNAUX D'ELECTROMYOGRAMME POUR UTILISATION AVEC UN RESEAU D'ELECTRODES
(54) ELECTROMYOGRAM SIGNAL ANALYSIS METHOD AND SYSTEM FOR USE WITH ELECTRODE ARRAY



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Electromyogram signal analysis method and system for use with electrode array

Background of invention

1. Field of the invention

The present invention relates to electromyography (EMG) analysis methods and system in which EMG signals, that contain physiological information pertaining to the diaphragm, of reverse polarity obtained on opposite sides of the center of the striated muscle electrically active region are a) corrected for electrode filtering by implementing a weighting function and b) integrated/summed. The sum/power of the new signal will provide improvement of the signal to noise ratio and minimize influence of electrode filtering due to changes in the position of the electrode array relative to the muscle's electrically active region center. It also accounts for differences in anatomy between individuals and differences in inter-electrode distance and design.

2. Brief description of the prior art

The physiological mechanisms which generate myoelectrical activity when the muscle contracts have been known and understood for long time. In particular, how to record signals from the muscle is one of the most extensively theoretically described topics in physiology. Although the theoretical understanding is impressive, the bio-physiological application of these theories is, in practice, still partly deficient. As of today, we are only aware of one system for standardized and automatic processing which take into consideration factors as electrode filtering due to changes in the position of the electrode array relative to the muscle's electrically active region center. This technique is limited with respect to its adaptability to changes in inter-electrode distance and does not optimize the use of signals available along the electrode array with varying anatomy and interelectrode distance. The previous technology does not include the use of weighting functions to correct for inclusion of signals obtained from electrode pairs that are not symmetrically positioned with respect to the center of the muscle's electrically active region.

Objects of the invention

The object of the present invention is therefore to overcome the above described drawbacks in the prior art.

Summary of the invention

More particularly, in accordance with the present invention, there is provided a method and system for producing an electromyographic signal having improved signal to noise ratio related to a striated muscle defining a muscle electrically active region with a center and provide correction for filtering of the electromyographic signal due to the relative position of the electrode array with respect to the muscle's electrically active region center.

Electromyographic signals produced by the muscle are first detected by means of an array of electrodes passing through the center of the muscle electrically active region. Each electrode detected electromyographic signal comprises an electromyographic

electromyographic component and high noise component. Comparison of the area/power/amplitude of the added and subtracted signals provides information about the relative contribution of noise and electromyographic components in the signal. Signals considered as not containing physiological information pertaining to the diaphragm can be replaced by predicted values or simply the last value considered to contain physiological information pertaining to the diaphragm. This replacement strategy can be applied on either each single signal obtained from the electrode array or on the summation signal representative for all or some of the signals obtained along the electrode array.

Brief description of the drawings

In the appended drawings:

Figure 1 is a schematic representation of a setup of the EMG analysis system in accordance with the present invention; (same as Fig 1 in patent 5,671,752)

Figure 2 is a section of esophageal catheter on which an array of electrodes of the EMG analysis system of Figure 1 is mounted; (same as Fig 2 in patent 5,671,752)

Figure 3 is showing a set of EMG signals of the diaphragm detected by pairs of successive electrodes of the array of Figure 2; (same as Fig 3 in patent 5,671,752)

Figure 4 to this flow chart showing a method for determining the position of the center of the electrically active region of the diaphragm along the array of electrodes of Figure 2; (same as Fig 4 in patent 5,671,752)

Figure 5 is a graph showing the distribution of correlation coefficients calculated for determining the position of the center of the electrically active region of the diaphragm along the array of electrodes of Figure 2; (same as Fig 5 in patent 5,671,752)

Figure 6 is a graph showing measured electrode filtering effects along the electrode array for arrays of various interelectrode distances; (enclosed figure 6)

Figure 7 is a graph showing measured and predicted electrode filtering effects along the electrode array; (enclosed figure 7)

Figure 8 is a flow chart showing the steps of signal processing; (enclosed figure 8)

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component and a noise component, and the position of the center of the muscle electrically active region can be detected through a reversal of polarity of the electromyographic components of the electrode detected electromyographic signals.

The area/power of each electromyographic signal obtained on either side of the electrically active region center, is multiplied/divided by a weighting function. The weighting function is derived from a mathematical model for a perpendicular bipolar transfer function and adjusts the area/power of each electromyographic signal with respect to the relative position of the electrode array with respect to the muscle's electrically active region center. The final signal is then obtained by calculating the sum/mean values of all the corrected area/power of each electromyographic signal obtained on the electrode array. The processing can be performed in the time domain or in the frequency domain.

The weighting function contains correction for electrode filtering due to a) the relative location of the electromyographic signals electrically active region center to the electrode pairs used to obtain a differential signal, b) distance filtering between signal source and electrodes, c) size of the electrically active region and, d) inter-electrode distance. Knowing the position of the electrically active region the model can produce weighting functions correcting for both cancellation effects and distance damping effects.

An evaluation of all electromyographic signals can be performed on the signals for their relative components of electromyographic signals and noise signals. Thus, if preferred the summation of signal area/power along the electrode array can be limited to signals that contain physiological information pertaining to the diaphragm. This evaluation of signals content can be performed by applying signal quality indexes for detection of signal noise ratio maximum to minimum drop in power density, power spectrum deformation, and electrocardiogram/esophageal peristalsis detectors. These have been previously described in Patent 5,671,752. Evaluation of signals for their relative components of electromyographic signals and noise signals can also be obtained by subtracting signals obtained on opposite sides with symmetrical position to the electrically active region center and comparing the area/power of the subtracted/added signals (This have previously been described in Trigger patent application). If a first electromyographic signal detected by the electrodes of the array on the first side of the center of the electrically active region is subtracted from a second electromyographic signal detected by the electrodes of the array on the second side, opposite to said first side, of the center of the electrically active region. The first electromyographic signal has an electromyographic component of a first polarity, and since the second electromyographic signal has an electromyographic component of a second polarity opposite to the first polarity. The subtraction subtracts the noise components of the first and second electromyographic signals from each other but adds the respective electromyographic polarity. The addition adds the noise components of the first and second electromyographic signals together produce a signal with high electromyographic component and low noise component. The addition adds the noise components of the first and second electromyographic signals to each other but subtracts the respective electromyographic component of the first and second electromyographic signals from each other and produces a signal with low

"disclosure"

Wanted signals (S) and signals (D) from disturbing structures are recorded with an electrode array having N electrode plates labeled n=1 to N. The array does not have to be linearly arranged; any configuration may be used.

The signal recorded at a certain electrode plate (n) depends on 1) the properties of the wanted signal source and the disturbing signal source (point sources or line sources with particular direction or curved line sources) and on 2) the distances ($r_d(n)$ and $r_s(n)$, respectively) from the sources to the electrode plate (n). Line source signals display a mixed frequency and distance dependent damping essentially described by modified Bessel functions while point source signals are damped inversely proportional to the distance and independent of frequency.

Each electrode plate is passed through a weighting function ($W(n)$, a frequency dependent filter) which may be positive negative or even zero prior to a summation of all contributions (n=1 to N) to give the output signal.

Describing the signal conditioning in the spectral domain (frequency dependence) we have the following expressions:

the signal $u(n)$ at electrode plate (n) is

$$u(n) = S f_d[r_d(n)] + D f_s[r_s(n)]$$

the output signal (Out) is:

$$\text{Out} = \sum_{n=1}^N u(n) W(n)$$

Combining the two equations and rearranging the terms give

$$\text{Out} = S \sum_{n=1}^N f_d[r_d(n)] W(n) + D \sum_{n=1}^N f_s[r_s(n)] W(n)$$

In general terms, for a good performance, we have to maximize the first term and minimize the second one, or depending on the application at hand, utilize known filtering strategies to optimize the spectral distributions of wanted and disturbing signals. The optimization is performed by varying signal strength and spectral (complex) contents of the weighting filters $W(n)$. This process can be guided by a priori knowledge of the type of signal source (line, point, etc) and the corresponding type of damping (modified Bessel functions, inverse distance damping, etc) and/or experimental knowledge of the signals spectral content.

One extreme situation occurs when no frequency dependence is assumed and the weighting factors are plus or minus unity. This is the situation in the so-called double subtraction technique used for picking up signals from the diaphragm muscle with the electrode array perpendicular to the muscle fiber direction. This simple double subtraction also has the property of reducing signals coming from outside the group of electrodes.

The use of electrode arrays of arbitrary configuration in combination with the use of weighting functions which are also frequency dependent to optimize the signal-to-disturbance ratio of the output signal.

The use of summation of weighted contributions from an electrode array of arbitrary configuration in such a way (weighting functions with different sign, strength, and spectral responses) that the wanted signal is enhanced and the unwanted signals are suppressed.

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WHAT IS CLAIMED IS:

1. A method of producing a higher quality
5 electromyographic signal describing myoelectrical activity of an electrically active region of a subject's muscle, comprising:
sensing through an array of electrodes a plurality of EMG signals representative of the myoelectrical activity of the electrically active region of the subject's muscle;
10 applying a weighting function to the detected EMG signals and thereby producing weighted signals, the weighting function containing correction features for the relative locations of the electrically active region and the electrodes; and
combining the weighted signals and thereby producing the
15 higher quality electromyographic signal.
2. A method of producing a higher quality
electromyographic signal as defined in claim 1, wherein:
the electrically active region of the subject's muscle
20 comprises a center,
the electrodes are separated from the center of the electrically active region by respective distances;
the electrodes are separated from each other by an inter-electrode distance; and
25 the weighting function comprises correction features for:
-- the relative location of the center of the electrically active region and the electrodes;
-- the distance separating the center of the electrically active region and the electrodes;
-- the size of the electrically active region; and
30 -- the inter-electrode distance.

3. A method of producing a higher quality
electromyographic signal as defined in claim 1, wherein the weighting function
comprises correction features for both cancellation and distance damping
effects.
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4. A method of producing a higher quality
electromyographic signal as defined in claim 1, wherein the electrically active region of the subject's muscle comprises a center, the array of electrodes comprises a series of electrodes with an inter-electrode distance, each EMG
10 signal is detected through at least two electrodes of the array, and wherein applying the weighting function comprises:
detecting the position of the center of the electrically active region about the array of electrodes;
relating the weighting function to the position of the center
15 of the electrically active region with respect to the electrodes of said series;
weighting each EMG signal by means of the weighting function related to the position of the center of the electrically active region with respect to the electrodes of said series.
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5. A method of producing a higher quality
electromyographic signal as defined in claim 4, wherein the series of electrodes has a center, and wherein, when the center of the electrically active region is offset with respect to the center of the series of electrodes:
25 a larger number of EMG signals are detected by the electrodes on one side of the center of the electrically active region so than on the other side of said center of the electrically active region so that EMG signals are missing on said other side; and
weighting of the EMG signals comprises replacing the
30 missing EMG signals on said other side by corresponding EMG

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signals from said one side and subsequently weighing said replacement EMG signals.

5 6. A method of producing a higher quality electromyographic signal as defined in claim 1, wherein combining the weighted signals comprises:
adding a feature of the weighted signals together.

10 7. A method of producing a higher quality electromyographic signal as defined in claim 1, wherein combining the weighted signals comprises:
calculating a mean of a feature of the weighted signals.

15 8. A method of producing a higher quality electromyographic signal as defined in claim 1, further comprising, prior to combining the weighted signals, evaluating electromyographic quality of the weighted signals.

20 9. A method of producing a higher quality electromyographic signal as recited in claim 8, wherein evaluating electromyographic quality comprises applying to the weighted signals quality indexes for detection of at least one of the following parameters:

- signal-to-noise ratio;
- maximum-to-minimum drop in power density;
- power spectrum deformation;
- electrical activity related to electrocardiogram/esophageal peristalsis.

30 10. A method of producing a higher quality electromyographic signal as recited in claim 8, wherein the electrically active

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region of the subject's muscle comprises a center, and wherein evaluating electromyographic quality comprises adding to each other two of the weighted signals detected through respective electrodes situated on opposite sides of the center of the electrically active region to produce a corresponding addition

5 signal, subtracting said two weighted signals from each other to produce a corresponding subtraction signal, and comparing said addition and subtraction signals, said comparison being representative of the electromyographic quality of the weighted signals.

10 11. A method of producing a higher quality electromyographic signal as recited in claim 8, further comprising, prior to combining the weighted signals, replacing the weighted signals whose evaluated quality is insufficient.

15 12. A method of producing a higher quality electromyographic signal as recited in claim 11, comprising replacing the weighted signals whose evaluated quality is insufficient by predicted values.

20 13. A method of producing a higher quality electromyographic signal as recited in claim 11, comprising replacing the weighted signals whose evaluated quality is insufficient by a fast value of said weighted signals considered as containing electromyographic information.

25 14. A method of producing a higher quality electromyographic signal as recited in claim 8, comprising replacing the higher quality electromyographic signal in response to weighted signals of insufficient quality.

30 15. A system for producing a higher quality electromyographic signal describing myoelectrical activity of an electrically active region of a subject's muscle, comprising:

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an array of electrodes for sensing a plurality of EMG signals representative of the myoelectrical activity of the electrically active region of the subject's muscle;

a weighting filter applied to the detected EMG signals to produce weighted signals, the weighting filter containing correction features for the relative locations of the electrically active region and the electrodes; and

a combiner of the weighted signals, the combined weighted signals constituting the higher quality electromyographic signal.

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16. A system for producing a higher quality electromyographic signal as defined in claim 15, wherein: the electrically active region of the subject's muscle comprises a center;

the electrodes are separated from the center of the electrically active region by respective distances;

the electrodes are separated from each other by an inter-electrode distance; and

the weighting filter comprises correction features for:

- the relative location of the center of the electrically active region and the electrodes;
- the distance separating the center of the electrically active region and the electrodes;
- the size of the electrically active region; and
- the inter-electrode distance.

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17. A system for producing a higher quality electromyographic signal as defined in claim 15, wherein the weighting filter comprises correction features for both cancellation and distance damping effects.

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18. A system for producing a higher quality electromyographic signal as defined in claim 15, wherein: the electrically active region of the subject's muscle comprises a center;

the array of electrodes comprises a series of electrodes with an inter-electrode distance;

each EMG signal is detected through at least two electrodes of the array; and

the weighting filter comprises a weighting function related to the position of the center of the electrically active region with respect to the electrodes of said series.

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19. A system for producing a higher quality electromyographic signal as defined in claim 15, wherein the series of electrodes has a center, and wherein, when the center of the electrically active region is offset with respect to the center of the series of electrodes:

a larger number of EMG signals are detected by the electrodes on one side of the center of the electrically active region than on the other side of said center of the electrically active region so that EMG signals are missing on said other side; and

the system comprises means for replacing the missing EMG signals on said other side by corresponding EMG signals from said one side, and means for subsequently weighting said replacement EMG signals.

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20. A system for producing a higher quality electromyographic signal as defined in claim 15, wherein the combiner comprises:

an adder of a feature of the weighted signals.

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21. A system for producing a higher quality electromyographic signal as defined in claim 15, wherein the combiner comprises:

a calculator of a mean of a feature of the weighted signals.

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22. A system for producing a higher quality electromyographic signal as defined in claim 15, further comprising, prior to combining the weighted signals, an evaluator of an electromyographic quality of the weighted signals.

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23. A system for producing a higher quality electromyographic signal as recited in claim 22, wherein the evaluator comprises means for applying to the weighted signals quality indexes for detection of at least one of the following parameters:

- signal-to-noise ratio;
- maximum-to-minimum drop in power density;
- power spectrum deformation;
- electrical activity related to electrocardiogram/esophageal peristalsis.

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24. A system for producing a higher quality electromyographic signal as recited in claim 22, wherein the electrically active region of the subject's muscle comprises a center, and wherein the evaluator comprises an adder of two of the weighted signals detected through respective electrodes situated on opposite sides of the center of the electrically active region to produce a corresponding addition signal, a subtractor of said two weighted signals from each other to produce a corresponding subtraction signal, and a comparator of said addition and subtraction signals, this comparison being representative of the electromyographic quality of the weighted signals.

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25. A system for producing a higher quality electromyographic signal as recited in claim 22, further comprising means for replacing, prior to combining the weighted signals, the weighted signals whose evaluated quality is insufficient.

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26. A system for producing a higher quality electromyographic signal as recited in claim 25, comprising means for replacing the weighted signals whose evaluated quality is insufficient by predicted values.

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27. A system for producing a higher quality electromyographic signal as recited in claim 25, comprising means for replacing the weighted signals whose evaluated quality is insufficient by a last value of said weighted signals considered as containing electromyographic information.

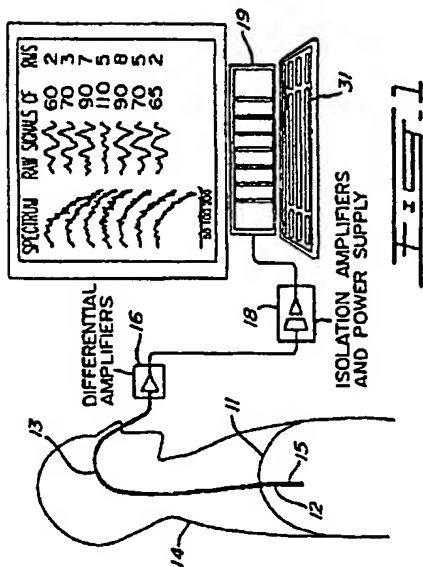
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28. A system for producing a higher quality electromyographic signal as recited in claim 22, comprising means for replacing the higher quality electromyographic signal in response to weighted signals of insufficient quality.

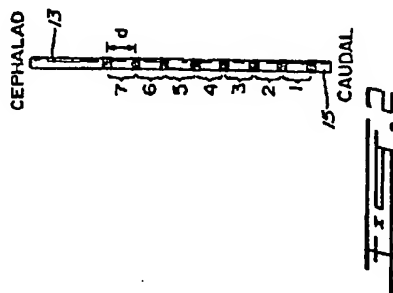
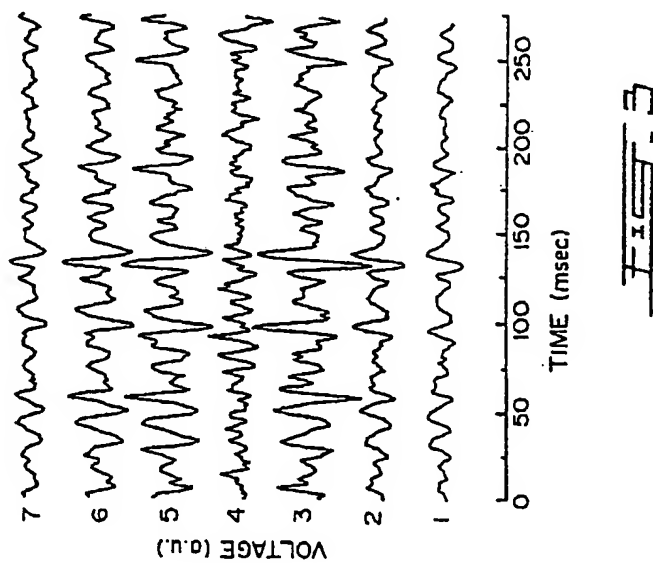
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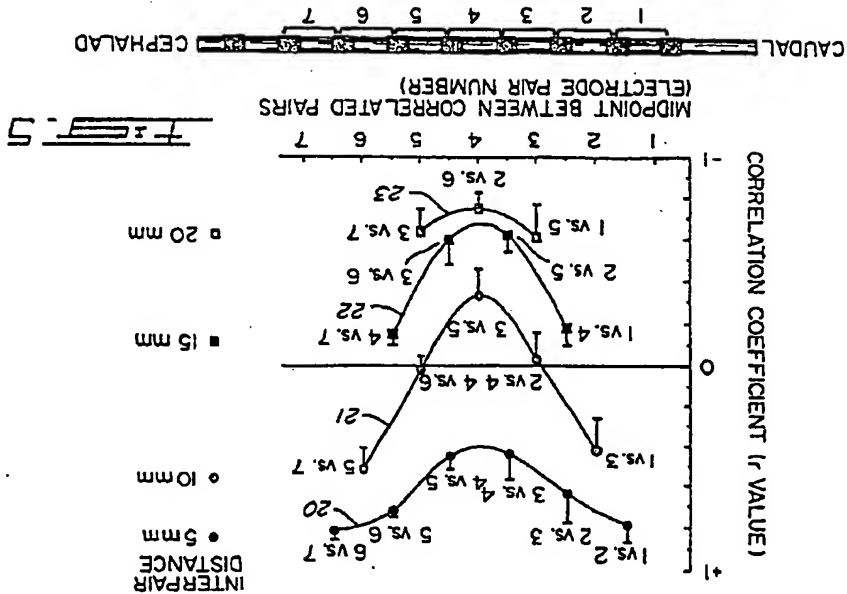
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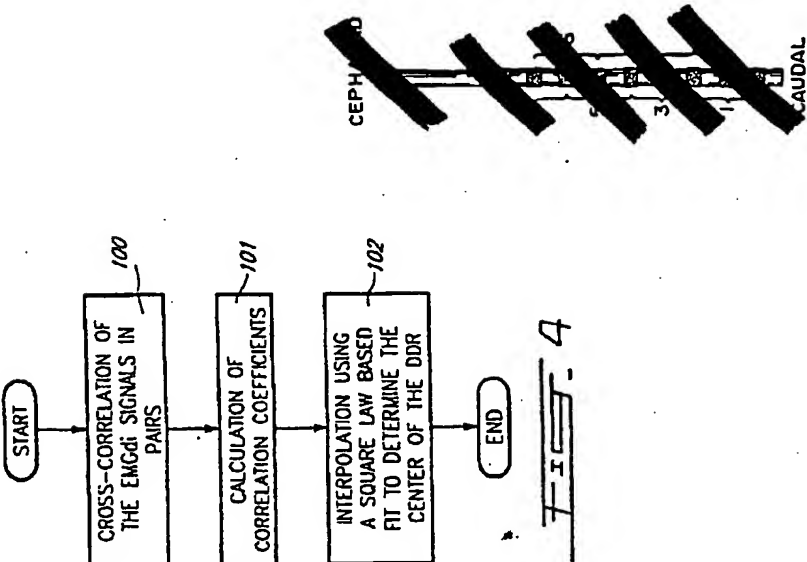


Fig 7

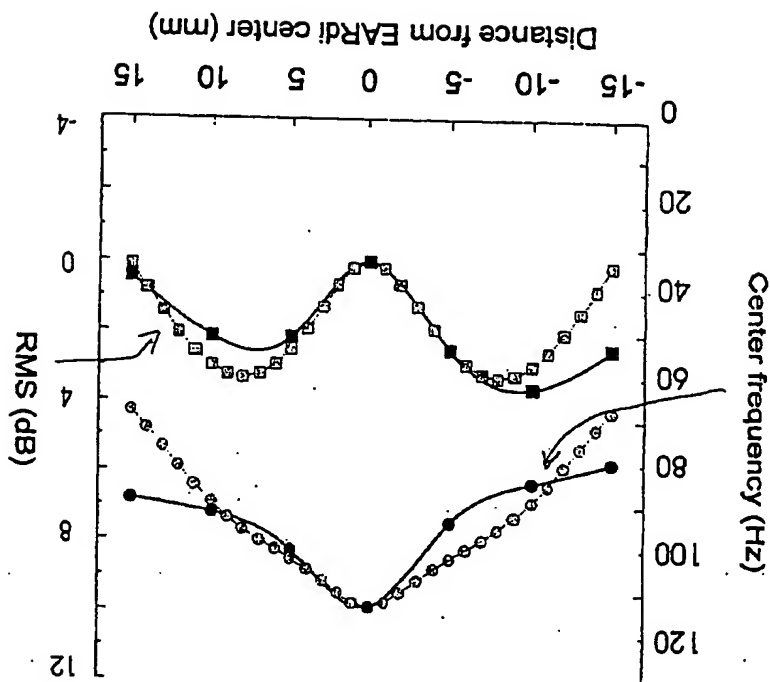


Fig 6

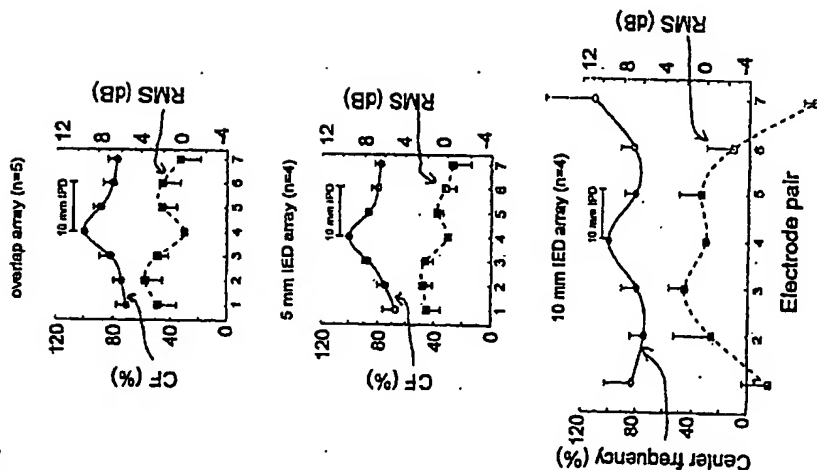
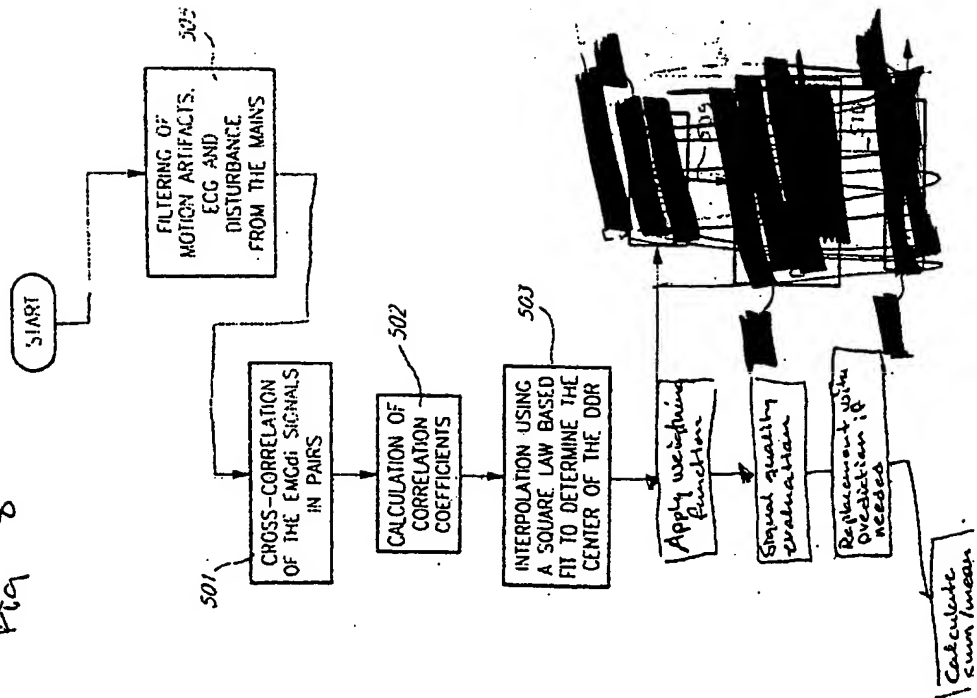


Fig 8



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